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XVI.

OBSERVATIONS ON JUPITER.

BY L. TROUVELOT.

Presented March 9, 1881.

IN the year 1876, a series of observations on the planets Mercury, Venus, Mars, Jupiter, and Saturn was undertaken with the intention of following each one of these bodies for as many years as necessary to study them on every point of their orbit, in order to arrive at a better knowledge of their physical constitution and meteorology. The plan then formed was to make at least one observation and a drawing of each planet on every favorable day, whenever the object would be so situated that it could be advantageously observed. So far, this plan has been carried out, and over 1,500 observations, accompanied by 1,000 drawings, have been made.

It is my purpose in this paper to make as brief a statement as possible of those portions of my observations pertaining to the rotation of Jupiter, and the great red spot which made its appearance upon its surface in the year 1878; reserving the rest for publication whenever means shall be found for printing the plates in a suitable manner.

The facts here recorded were selected from the 591 observations and 567 drawings of the series made during the last five years.

The year 1876, the first of my regular and systematic observations of Jupiter, was one of extraordinary disturbance, and nothing approaching it has since been witnessed. The changes were so rapid that, save in one case, no spots or markings could be recognized the day, nay, sometimes even the hour, after they had been observed. Since that time, the surface of the planet has been remarkably quiet, only an occasional change taking place. During the last four years some of the markings have been very persistent, and remained in sight for years, with but very little apparent change.

MARK A.

In one case only, as has been said above, was a spot recognized in 1876. This object, first seen on May 19, was recognized on May 21,

after having accomplished five rotations, the mean of which equals $9^h 47^m 0^s$. The position of this spot was in the northern part of the equatorial belt, extending as far as its border on that side. For convenience we will call this marking A: the other markings to be described will be similarly designated by a letter of the alphabet.

MARK B.

In contrast with the usual behavior of the spots seen on the surface of Jupiter in years of calm, and also to show how much these spots are to be relied upon to determine the period of rotation of the planet, I will give a brief account of an observation made in 1876, from which an idea can be formed of the rapidity with which changes sometimes take place on Jupiter, and of the swiftness which sometimes animates these spots.

On May 25, Jupiter was observed and a drawing made at $8^h 37^m$. At this time, and at least five minutes later, nothing unusual or remarkable was to be seen on the planet. At $9^h 4^m$, however, an angular marking resting on the outside border of the equatorial belt, on its south side, was visible near the east limb. This mark advanced rapidly towards the centre of the disk, which it had passed at $9^h 32^m$, when a third drawing was made. At $9^h 50^m$ the angular marking had reached the western limb, having then crossed the disk of Jupiter from east to west in less than an hour's time.

The angular mark of which the motion has just been described was formed by an oblique dark band, resting on its preceding side on the upper band, forming the southern margin of the equatorial belt. As the angular mark advanced on the disk, the space behind it enlarged considerably, the upper band limiting it southwards, keeping the same obliquity with the equatorial belt as far as it could be seen on the east limb. At $9^h 32^m$ the oblique band on the east limb had a latitude of 50° south. After the angular mark had crossed the western limb, it continued its tremendous onward motion, as could be seen by the constantly increasing latitude of the upper band on the west limb, and at $10^h 20^m$ this upper band was parallel with the southern border of the equatorial belt. The space then comprised between this upper band and the southern margin of the equatorial belt was equal to 35° , and was about twice as broad as the latter belt before the disturbance occurred. This space appeared tinted with a delicate pink color, intermingled with white cumulus-like spots resembling exactly those usually seen on the equatorial belt. When the upper band reached

parallelism with the equatorial belt, at $10^h 20^m$, the pink color formed a wide belt extending from 10° of north latitude to 45° of south latitude, being therefore 55° in breadth.

Not only that zone of Jupiter was in commotion, but the whole of the southern hemisphere participated in it up to the pole, as proved by the total change of the markings, and the swelling of all the bands to higher southern latitudes on their following side. One of the bands, which on the western limb was at 30° south, was swollen to the south pole on its following extremity. It is to be noted that, in this great disturbance, the bands, although enormously swollen on the following side, still maintained the same distance from each other; each one keeping pace with the other, and following it in all its sinuosities, the effect being apparently the same as if a wedge had been driven from east to west between the upper border of the equatorial belt and the oblique band described. On many occasions in 1876, this continuous parallelism between the different bands in the midst of disturbances was observed, as if the force causing the disturbance had been moving from east to west, between the vapory envelope of Jupiter, and pushing it aside in its passage, as a ship parts the waves of the ocean.

On the following day no traces of this great storm appeared; but everything seemed quiet, the equatorial belt having resumed the same appearance it had on the 25th, before the commotion occurred.

If we determine the period of rotation of Jupiter from the observations of this angular marking, which will be called B, it is found to be very nearly two hours, a period which is very far from agreeing with that found by the observations on the mark A above described, and the adopted period until lately, viz. $9^h 55^m 41^s$. The last two periods may be called the periods of calm, while the first may be called the period of disturbance.

MARK C.

In 1876 the observations on Jupiter were discontinued after Oct. 19, and resumed after conjunction, on April 11, 1877. On that day a very characteristic mark, resembling a step seen in profile, was observed on the southern border of the equatorial belt, which at one point was deflected at a right angle, the western portion of the belt, or preceding side, being narrower than the eastern or following side.

This step-like marking, which will be called C, was a new form, which had not once been seen in 1876. It remained visible through-

out the year 1877 as late as Dec. 2, when the observations were abandoned, owing to the proximity of Jupiter to the Sun. In 1878, only a few scattered observations were made from the 10th of February to the end of August, the work being resumed regularly in September only. On the 10th, a step-like marking, resembling that observed the year before, was seen on the southern border of the equatorial belt, apparently at the same place which that mark occupied. It was probably the same object, as seems to result from the calculation of its period of rotation, and from its position in regard to the mark D, which will be next described.

In the following table are given the dates and times of the passages of the mark C on the central meridian. Similar tables will be given for the other markings described in this paper. The passages of the markings or spots on the central meridian have not been obtained by micrometrical measurements, but are simple eye estimations. This, of course, renders them liable to errors, which cannot, however, exceed two minutes in most cases, I think.

The passages tabulated have not all been obtained by direct telescopic observations in the way described just now, about one third only having thus been observed. The others were obtained afterwards from the drawings themselves, the marking being reduced to the meridian from its position on the drawing, either east or west of the centre. These passages, of course, are liable to still larger errors than the former, the chances for error becoming greater as the distance from the centre increases. For this reason, the position of the markings at the time of observation, that is to say, their distance in time east or west of the central meridian, is given after each passage thus obtained; the symbol + indicating that it had passed the meridian, and was west of it by the time given when the observation was made; and the symbol — indicating that it was east of it, and had not yet reached the meridian, which it would cross only after the time given had elapsed. The passages on the central meridian which were obtained by direct telescopic observation in the manner above described are distinguished from the others by the words "On meridian" placed in the third column.

The time given throughout this paper is the local time, or Cambridge mean time. The above remarks apply to all observations and markings tabulated, as well as the arrangement here adopted.

On July 25 some changes were observed in the mark C, also on Sept. 16 and 21, when the changes were most striking; possibly a jump may be found on these dates.

| | | h. m. | h. m. | | | h. m. | h. m. |
|----------------|--|-------|--------------|----------------|--|-------|--------------|
| 1877, April 11 | | 15 50 | On meridian. | 1877, Sept. 12 | | 6 5 | + 1 0 |
| " May 3 | | 14 10 | + 1 8 | " " 13 | | 8 37 | — 1 40 |
| " " 22 | | 14 45 | + 0 30 | " " 16 | | 6 40 | + 0 10 |
| " July 3 | | 9 22 | + 0 15 | " " 21 | | 6 40 | + 0 30 |
| " " 22 | | 10 3 | + 0 43 | " " 30 | | 7 35 | — 1 10 |
| " " 25 | | 15 45 | + 0 50 | " Oct. 10 | | 6 2 | — 0 12 |
| " Aug. 6 | | 16 17 | + 0 5 | " " 15 | | 5 0 | — 0 30 |
| " " 8 | | 17 37 | + 0 7 | " " 17 | | 6 50 | On meridian. |
| " " 10 | | 19 46 | — 1 0 | " " 27 | | 5 30 | On meridian. |
| " " 11 | | 15 49 | + 1 30 | " Nov. 3 | | 5 52 | — 0 10 |
| " " 18 | | 6 50 | + 1 30 | " " 15 | | 6 30 | — 1 05 |
| " " 22 | | 10 45 | — 0 30 | " " 20 | | 4 55 | + 0 25 |
| " " 30 | | 7 10 | On meridian. | " Dec. 2 | | 4 58 | On meridian. |
| " Sept. 4 | | 6 12 | + 0 50 | 1878, Sept. 10 | | 6 12 | + 0 48 |
| " " 11 | | 7 5 | On meridian. | | | | |

The mean period of rotation given by mark C, as obtained from 567 rotations, from April 11 to Dec. 2, equals $35,740.5^s$ or $9^h 55^m 40.5^s$. By taking the whole period of observations from April 11, 1877, to Sept. 10, 1878, we have 1,249 rotations, the mean of which is over four seconds and a half less, or $9^h 55^m 35.9^s$.

MARK D.

Another permanent and characteristic marking was also observed in 1877 on the southern border of the equatorial belt, following the step-like mark C, above described, at a distance of about 80 or 85 degrees. This mark was of an angular form produced on the preceding side by the straight border line of the broader part of the equatorial belt, and the sloping curved line joining the broadest to the narrowest portion of this belt on the following side.

This angular mark, observed first on April 14, continued visible throughout the year 1877, and was seen as late as Nov. 6, when the observations were discontinued, owing to the proximity of Jupiter to the Sun. It was found again in 1878, on Sept. 8, when I resumed my regular observations; and it continued to be seen through that year, and also in 1879, until the end of August, when it slowly disappeared, the equatorial belt then resuming its usual uniform width throughout.

It is impossible from my observations to know the exact time of the first appearance of this mark, but it is certain that it was not once seen in 1876 from the end of March to the 19th of October, although the planet was observed and drawn one hundred and twenty-five times during this interval.

Singularly enough I find a similar mark on the southern border of the equatorial belt, exactly represented in a drawing by Mr. Camille Flammarion, made on April 22, 1874, in Paris, and published in "Les Terres du Ciel," fig. 174, page 479. But unfortunately the time is not given; and, thus far, I have been unable to obtain it from its author. By assuming that the observation was made at eight o'clock, Paris mean time, and adopting the period of rotation of the similar mark observed by me in 1877-78, it is found that Mr. Flammarion's marking comes within fifty minutes of time of the place it should have occupied had it been the same object as that observed by me. Notwithstanding its disappearance in 1876, it does not seem unlikely that this is the same marking I observed three years later, or at least a recurrence of the same form at the same place, as it might be conceived to happen sometimes by the renewal of the same local causes.

Below is a table giving the dates and times of the passages of marking D on the central meridian.

| | h. m. | h. m. | | h. m. | h. m. |
|----------------|-------|--------------|---------------|-------|--------------|
| 1877, April 14 | 15 55 | + 0 35 | 1877, Sept. 2 | 6 50 | On meridian. |
| " " 26 | 16 15 | On meridian. | " " 4 | 8 35 | - 1 0 |
| " May 3 | 17 5 | - 0 35 | " " 9 | 7 15 | + 0 25 |
| " " 6 | 14 20 | + 1 0 | " " 14 | 6 25 | + 0 45 |
| " " 8 | 16 8 | - 0 30 | " " 26 | 6 0 | + 1 15 |
| " " 25 | 14 32 | + 0 45 | " " 29 | 5 20 | + 1 10 |
| " " 27 | 16 35 | - 0 30 | " Oct. 6 | 4 28 | + 1 0 |
| " " 30 | 13 55 | + 0 30 | " " 13 | 5 3 | + 0 42 |
| " June 11 | 13 10 | + 1 20 | " " 30 | 4 20 | + 1 20 |
| " " 18 | 14 22 | On meridian. | " Nov. 1 | 5 47 | - 0 12 |
| " " 20 | 13 40 | + 0 40 | " " 4 | 3 50 | + 1 30 |
| " " 23 | 13 0 | + 1 25 | " " 6 | 4 47 | + 0 33 |
| " " 24 | 9 10 | On meridian. | 1878, Sept. 8 | 5 35 | + 1 25 |
| " " 25 | 15 2 | - 0 42 | " " 20 | 7 5 | + 0 30 |
| " " 29 | 8 3 | + 0 47 | " " 25 | 6 10 | + 0 20 |
| " July 4 | 7 15 | + 1 10 | " " 30 | 5 0 | + 1 15 |
| " " 6 | 9 12 | - 0 30 | " Oct. 2 | 5 30 | + 0 50 |
| " " 15 | 11 23 | + 0 50 | " Nov. 12 | 5 50 | + 1 0 |
| " " 18 | 9 0 | On meridian. | " " 24 | 6 10 | On meridian. |
| " " 23 | 7 58 | + 1 12 | " " 29 | 4 55 | + 0 20 |
| " Aug. 4 | 16 47 | On meridian. | " Dec. 16 | 3 55 | + 1 0 |
| " " 6 | 18 24 | On meridian. | " " 23 | 4 52 | + 0 30 |
| " " 11 | 18 4 | - 0 45 | " " 28 | 3 55 | + 1 0 |
| " " 16 | 7 35 | On meridian. | 1879, May 25 | 15 45 | + 0 30 |
| " " 23 | 8 20 | On meridian. | " July 24 | 15 12 | + 0 23 |
| " " 26 | 5 40 | + 0 50 | " Aug. 21 | 8 5 | + 1 10 |
| " " 28 | 7 20 | On meridian. | | | |

On June 20, 1877, the mark D had its form greatly altered, and

then appeared a very different object, but the change was only temporary, as on the 23d it had resumed its former appearance. However, it is probable that some irregularity will be found on that date, and a jump may be noticed.

Between the 14th and 26th of September, 1877, the angular mark D was not seen, although ten observations and drawings were made during that interval. From calculation of the period of this mark, it is found that it should have been on the disk on the 16th, 19th, and 23d, at the time the observations were made. On the 16th, it should have been $1^h 16^m$ east of the centre; on the 19th, $2^h 9^m$ west, and on the 23d, $1^h 3^m$ east of it. If the marking had been visible, it certainly could not have escaped my observation on the 16th and 23d, when it was less than 40° from the centre, especially as the sight was very good at the time the observations were made. On the 19th, it might have passed unnoticed, as it must have been quite close to the limb and considerably foreshortened.

At the time the disappearance of this mark occurred, great changes were seen to be going on, in and about the equatorial belt, from which the disappearance probably resulted.

On the 26th, as already said, the mark was seen again, at the same place, and with precisely the same characteristic form it had from the beginning of my observations.

Again, from Nov. 6 to Dec. 9 of the same year, the same angular marking was not once seen, although the planet was observed and drawn thirteen times during this interval. Calculation showed that it should have been visible in November, on the 13th, 37^m east; on the 15th, $1^h 52^m$ east; on the 18th, 26^m west; on the 20th, $1^h 9^m$ east; and on the 30th, 15^m west of the central meridian; while in December it should also have been on the disk on the 2d, $1^h 34^m$ east, and on the 3d, $2^h 19^m$ west of the centre. But not the slightest traces of it were detected, although looked for; not even on the 13th, 18th, and 30th of November, when it should have been close to the central meridian.

On Nov. 13th, when this mark should have been near the centre, it was found that, at the very place it should have occupied, the southern margin of the equatorial belt was wavy, irregular, and somewhat swollen, but nothing looking like the familiar object so often observed was visible.

After Dec. 9, 1877, the observations were discontinued, Jupiter being too near the Sun to be observed with advantage, and were not regularly resumed after conjunction until Sept. 6, 1878.

Although scattered observations were made on Feb. 12 and 13, March 7 and 15, May 27, and June 13, no angular marking was seen. On Sept. 8, however, the same mark reappeared, and remained visible until the end of August, 1879.

On Sept. 10, the angular marking seen on the 8th should have been in sight, and within a few degrees of the central meridian, had it followed its regular proper motion; but it was not found on the disk. West of the meridian, however, the step-like mark C was visible, thus indicating that the angular mark was in the east very close to the limb. In order to have been at that place, the marks C and D, and perhaps the whole equatorial belt, must have moved backwards, and retrograded in these two days some 75° or 80° .

On the 25th of September, the great red spot was seen following very closely the angular mark D, and both kept their relative distance until the disappearance of the latter in the following year.

From the fact that this mark disappeared and re-appeared several times, it may be supposed that it was hidden from sight by opaque clouds or vapors floating high above it, and thus concealing it for some time. But the great jump observed between the 8th and 10th of September, 1878, shows that these markings, having no fixity at all, are liable to be transported to great distances by the forces at work on Jupiter, or to be destroyed and generated again afterwards; only, in the last case, it would seem singular that they should reappear in the same form.

THE GREAT RED SPOT, OR MARK E.

This curious and remarkable spot was seen by me for the first time on Sept. 25, 1878. Since then, I have drawn it one hundred and thirteen times in various positions upon the disk.

In the following table will be found the dates and times of the passages of the centre or of either of the extremities of this spot on the central meridian.

It would have been desirable to give in this paper the longitudes of the marks and spots at the time of their passage of the central meridian, as thus their proper motion and irregularities might have been easily ascertained. But as I had not an ephemeris at hand, giving the time when the assumed first meridian traversed the middle of the disk, of an earlier date than that of Sept. 18, 1880, I have been obliged to give the spots observed before that date without their corresponding longitudes. Those observed later, however, have their longitudes given in the last column, in which the daily rate of rotation is assumed to be 870.60° .

| | | | h. | m. | | | | |
|------|-------|----|----|----|----------------------------|----------|----------|--|
| 1878 | Sept. | 25 | 6 | 55 | Centre on meridian. | | | |
| " | " | 30 | 6 | 5 | " " " | | | |
| " | Oct. | 2 | 7 | 5 | " " " | | | |
| " | Nov. | 12 | 6 | 50 | Following end on meridian. | | | |
| " | " | 24 | 6 | 10 | Preceding " " | | | |
| " | " | 29 | 5 | 15 | " " " | | | |
| " | Dec. | 16 | 4 | 40 | Centre on meridian. | | | |
| " | " | 23 | 5 | 33 | " " " | | | |
| " | " | 28 | 4 | 45 | " " " | | | |
| 1879 | April | 7 | 17 | 25 | " " " | | | |
| " | May | 25 | 16 | 15 | Preceding end on meridian. | | | |
| " | July | 5 | 16 | 0 | Following " " | | | |
| " | " | 12 | 15 | 45 | Preceding " " | | | |
| " | " | 24 | 15 | 30 | " " " | | | |
| " | " | 29 | 15 | 45 | Following " " | | | |
| " | Aug. | 12 | 16 | 0 | Preceding " " | | | |
| " | " | 21 | 9 | 0 | Centre on meridian. | | | |
| " | Dec. | 7 | 7 | 20 | Preceding end on meridian. | | | |
| " | " | 12 | 6 | 26 | " " " | | | |
| " | " | 29 | 5 | 25 | " " " | | | |
| 1880 | Jan. | 3 | 5 | 11 | Centre on meridian. | | | |
| " | " | 5 | 6 | 20 | Preceding end on meridian. | | | |
| " | " | 8 | 4 | 45 | Following " " | | | |
| " | " | 10 | 5 | 25 | Preceding " " | | | |
| " | " | 24 | 7 | 4 | " " " | | | |
| " | " | 29 | 6 | 8 | " " " | | | |
| " | Feb. | 22 | 6 | 6 | " " " | | | |
| " | Aug. | 9 | 10 | 56 | Centre on meridian. | | | |
| " | " | 26 | 9 | 55 | " " " | | | |
| " | Sept. | 12 | 8 | 50 | " " " | | | |
| " | " | 17 | 7 | 56 | " " " | | | |
| | | | | | Preceding. | Centre. | | |
| 1880 | Sept. | 24 | 8 | 39 | 305 38.4 | 324 14.6 | | |
| " | " | 26 | 10 | 48 | . . . | . . . | 343 37.2 | |
| " | " | 29 | 7 | 44 | . . . | 324 7.2 | | |
| " | Oct. | 1 | 9 | 18 | . . . | 323 2.4 | | |
| " | " | 6 | 8 | 27 | . . . | 325 51.6 | | |
| " | " | 11 | 7 | 34 | . . . | 327 26.4 | | |
| " | " | 13 | 8 | 38 | 307 44.4 | | | |
| " | " | 18 | 8 | 16 | . . . | 327 26.4 | | |
| " | " | 23 | 7 | 23 | . . . | 329 16.8 | | |
| " | " | 28 | 7 | 6 | . . . | . . . | 352 12.0 | |
| " | Nov. | 1 | 9 | 52 | . . . | 335 20.4 | | |
| " | " | 2 | 5 | 40 | . . . | 333 39.6 | | |
| " | " | 8 | 10 | 35 | . . . | 335 49.2 | | |
| " | " | 9 | 6 | 20 | . . . | 332 16.8 | | |
| " | " | 16 | 7 | 7 | . . . | 334 58.8 | | |
| " | " | 18 | 8 | 47 | . . . | 336 36.0 | | |

| | | | | Preceding. | Centre. | Following. |
|------|------|----|------|------------|----------|------------|
| 1880 | Nov. | 21 | 6 16 | . . . | 337 1.2 | |
| " | " | 23 | 7 51 | . . . | 335 34.8 | |
| " | Dec. | 3 | 6 7 | . . . | 338 9.6 | |
| " | " | 7 | 9 29 | . . . | 342 18.0 | |
| " | " | 8 | 5 19 | . . . | 341 38.4 | |
| " | " | 15 | 6 4 | . . . | 342 18.0 | |
| " | " | 20 | 5 11 | . . . | 342 36.0 | |
| " | " | 27 | 5 35 | 330 21.6 | | |
| 1881 | Jan. | 1 | 5 12 | . . . | 348 32.4 | |
| " | " | 8 | 5 55 | . . . | 347 24.0 | |
| " | " | 10 | 8 10 | . . . | . . . | 12 18.0 |
| " | " | 20 | 5 52 | . . . | 350 20.4 | |
| " | Feb. | 13 | 5 50 | . . . | 0 32.4 | |
| " | " | 15 | 5 4 | 343 26.4 | | |

By comparing the time of the passages of the red spot on the meridian, given in the first part of the above table, with that given by Mr. A. Marth in the *Monthly Notices*, Vol. XL., No. 8, p. 496, a discrepancy will be found in the time of passage of Sept. 30, Oct. 2, and Dec. 16. I am unaware how this occurred, possibly through an error of mine; but the time should be corrected, that here recorded being right.

I have shown elsewhere * that the red spot must have disappeared in 1878, in the same manner as did the angular mark D in 1877. This spot, seen by different observers in July, August, and September, was not seen by me on Sept. 20; although, at the time my observation was made, it should have been very near the centre of the disk, and consequently in the best position to be observed. The very place where the red spot was seen five days later, was occupied by a dark irregular, gray band, commencing near the mark D, and extending east as far as the limb. As the sight was good at the time this observation was made, it cannot be supposed for a moment that it escaped my notice. If it had been there, it must certainly have been seen.

At the time of this observation, the red spot might have been concealed by the dark, irregular band already described, or it might have closed up, as the great variations observed in its size and form during the first year after its appearance would seem to suggest. At first the changes of form of the red spot were great and very frequent, and slowly and gradually it acquired the regular and comparatively steady shape it has shown for over a year.

* "On the Recurrence of some of the Markings on Jupiter." *The Observatory*, No. 24, April, 1879, p. 411.

When first seen on Sept. 25, 1878, it appeared as a long and narrow form, with a slender, sharp point on its preceding side. The time of the passage of this spot on the meridian, from its preceding to its following extremity, was on that day $1^h 18^m$. It retained this form more or less exactly for a few days, but on Oct. 2 it had considerably extended longitudinally, the narrow parallelogrammic form of its following side being prolonged on the preceding end by a very slender and acute point; the whole spot occupying apparently one half the diameter of the disk, and its passage over the meridian, from end to end, being $2^h 15^m$.

On Oct. 5 and 17 it was considerably shortened, and on Nov. 12 it was almost oval, with its preceding end pointed. On the contrary, on Nov. 24 its preceding end was cut square, while the following was sharply pointed. On Nov. 29, the preceding end was rounded, while the following was obliquely cut.

On Dec. 16, the form of the red spot was found completely changed, it having two large protuberant masses projecting from its northern margin. One, the larger, was near the following end; the other, smaller, near the preceding end, which was pointed. On Dec. 23, the spot had somewhat diminished in size, and had three protuberances on its northern border, instead of two; but they were a little smaller than those of the 16th. The major axis of the red spot, which, so far, had been parallel to the equatorial belt, was on that day considerably tilted, and inclined to it 20° or 25° , its preceding end being the nearest to the equator. On Dec. 28 and 30, the spot had enlarged considerably, keeping, however, about the same irregular shape, except that it was more pointed on the preceding side, and that the three projections on its northern side were larger. The axis-major of the spot had then resumed its parallelism with the equatorial belt.

On April 7, 1879, the red spot appeared elliptical, although very little elongated; while on May 25 its form was that of a very extended narrow parallelogram having both ends slightly rounded. On July 5, it was oval in shape, or rather egg-form, its preceding end being much wider than the following.

Between this last date and the middle of August, it was constantly changing, but the changes were very slight. On Aug. 21, its preceding end was forked or swallow-tailed, while the following was pointed. On Aug. 28, it had a regular and beautiful oval form. On Dec. 8, it appeared narrower and more extended longitudinally, its delicate color having somewhat lost its purity.

About the beginning of January, 1880, the red spot began to assume the regular oval shape which it has, with but very slight modifications, since retained. These modifications of form consisted principally in that one of its ends appeared narrower, giving it therefore an egg-shape, as that observed on the 1st of November. Its northern margin has also frequently been observed to be deformed, appearing jagged and indented, principally on Aug. 26, Sept. 29, and Dec. 10 of last year. The serrations, projecting on the red spot, sometimes appeared as bright nodules, as if the narrow band separating the red spot from the equatorial belt had been composed at these times of brilliant cumulus-like forms having a higher level than the spot itself.

Although comparatively steady now, the red spot varies almost from day to day in length, as well as in breadth; but most of the time the variations are so slight that the greatest attention is required to notice them, and for most observers it is only once in a while that they become apparent.

The color of the red spot is also subject to some variations, but usually they are slight; and, as these phenomena are more delicate than mere changes of form, it usually requires an expert and trained eye to see them. Apart from the changes in the intensity of its color, which are quite frequent, the variations of color which came under my notice are few, the greatest being, as stated above, when the clear red color of the spot lost its purity, and became muddy and *lie-de-vin* color. Most of the time, the variations in the intensity of the red spot could be attributed to the state of our atmosphere, but sometimes, as in the above case, they seemed to be real, as the pink color of the equatorial belt was not affected, as it would have been if the cause were atmospherical. It will be shown below that sometimes, also, the pink color of the equatorial belt increases considerably in some parts, while it remains unchanged in others.

Throughout the whole month of November, 1880, I had the persistent impression that there were two small, round, black spots, or specks, on the red spot; one being not far from its preceding end, while the other, behind, was a little to the west of its middle, both appearing to be a little nearer the southern than the northern border. On Nov. 30, I had the satisfaction of finding that my impressions were correct, as I plainly and distinctly saw two small, round spots at the place where I had perceived them so many times before. One of these black specks was observed independently by Mr. Alvan Clark, Jr., on

the night of Jan. 5, 1881, with the twenty-two inch refractor he is now constructing for the Princeton Observatory.

On Nov. 1, 1880, the pink color of the northern portion of the equatorial belt, situated above the black spots G, which will be described below, became very intense, and upon it were seen many small black spots and specks resembling those observed on the red spot on the same day, and throughout the months of November and December of the same year.

The red spot has sometimes appeared surrounded by a white ring, which varied in brightness and width. At times it became very brilliant, and appeared as if mottled over by some cloudy specks. This white ring was especially conspicuous in January, October, and November, 1880. From its appearance and brilliancy, it would seem that this luminous ring is formed by an accumulation of clouds, having a higher level than the surrounding surface, and especially that of the red spot. It might be interesting to watch the transit of the shadow of satellites across the common boundary line separating the red spot from the ring, and see if the shadow is deformed by a change of level. But the delicacy of such an observation would be very great, and probably only large instruments could attempt it. On Aug. 24, 1880, I saw the shadow of Satellite I. passing on the thin, white belt separating the red spot from the equatorial belt, and projecting about one third of its disk on the red spot; but I was unable to detect any distortion of its shape, the sight being poor at the time. On Nov. 1 of the same year, the shadow of Satellite II. was observed in transit on the red spot; nothing unusual in its shape was noticed. The most favorable opportunity for such a delicate observation would be when Jupiter is near its quadratures, and the red spot close to the limb. At such a time, the shadow of a satellite crossing the extremity of the red spot nearest to the limb would be seen under its greatest possible distortion. If there be a change of level between the ring and the red spot, it ought, it seems, to be noticeable under good atmospheric definition, but transits under these conditions must necessarily be very rare.

While treating the subject of the red spot, I should not omit to say that this object has not always been unique. While in the Paris Observatory, on Sept. 18 or 19, 1879, I had an opportunity of observing Jupiter with an excellent refractor of eight or nine inches' aperture made by MM. Henri Brothers. At the moment the observation was made, the great red spot was a little to the east of the middle of the disk. Right above and a little preceding it were two small, roundish

red spots, one larger than the other, each surrounded by a brilliant and narrow white ring. I called the attention of the MM. Henri to this fact, which both easily verified. The color of these two small spots was not that of the equatorial belt, which is of a different shade and much less intense, but precisely the same as that of the great red spot, which they, with their bright ring, resembled in miniature. It will be seen below that the pink color sometimes appears instantly in different parts of the disk, and this even in high latitudes.

Allowing for errors of observation, and taking them into account, it is found that the period of rotation of the red spot is irregular, and varies somewhat on certain days, while on others no variation is perceptible. This shows that the red spot, like all other spots described in this paper, is not fixed on the planet, and changes place under the action of internal or external forces.

The mean period of rotation of this spot seems to have slowly decreased for some time. From the end of September to the end of December, 1878, the mean period of rotation is found to be $9^h 55^m 43.61^s$; from the end of December, 1878, to the beginning of January, 1880, the mean period was $9^h 55^m 36.85^s$. But from January, 1880, to February, 1881, it is found to be $9^h 55^m 38.96^s$. The mean period of rotation from the whole being approximately $9^h 55^m 38.57^s$.

MARK F.

Besides the great red spot E, and the markings C and D, which were conspicuous and permanent objects, other spots of shorter duration have also been observed, and their proper motion carefully watched.

One of the most characteristic among them appeared inside the equatorial belt, close to its southern border. It consisted of a very bright, round spot, forming the preceding extremity of one of the white, cloud-like spots which constitute the middle zone of the equatorial belt. This bright object protruded considerably southwards on the rosy background of the equatorial belt, and as far as its southern border, which it seemed sometimes to push out and swell at that point.

This spot, although it very likely existed before, was particularly noted on Nov. 16, 1880, and was watched until it disappeared. By going backward and examining the drawings anterior to that date, it was found that one of the markings, much resembling the mark F, was observed as far back as Aug. 8 of the same year, although it was not so brilliant at that time as it has been since, if it is the same spot. As it is thought to be the same object, I will give

the times of its observed passages on the central meridian, together with those observed after the 16th.

| 1880. | h. m. | h. m. | ° | ' | 1880. | h. m. | h. m. | ° | ' |
|---------|-------|--------------|-----|------|--------|-------|-------------|-----|------|
| Aug. 28 | 9 30 | On meridian. | | | Dec. 7 | 5 31 | On meridian | 199 | 30.0 |
| Oct. 18 | 7 44 | + 0 32 | 308 | 38.4 | " 9 | 6 25 | + 0 27 | 173 | 56.4 |
| " 25 | 6 26 | + 0 40 | 236 | 52.8 | " 14 | 4 45 | On meridian | 145 | 33.6 |
| Nov. 7 | 7 17 | — 0 30 | 67 | 33.6 | " 16 | 5 57 | " " | 130 | 8.4 |
| " 16 | 7 37 | — 0 30 | 352 | 58.8 | " 23 | 4 58 | " " | 68 | 9.6 |
| " 18 | 8 53 | — 0 6 | 340 | 12.0 | " 30 | 4 23 | + 0 33 | 20 | 27.6 |
| " 21 | 5 36 | + 0 40 | 313 | 1.2 | 1881. | | | | |
| " 23 | 6 43 | + 1 8 | 294 | 46.8 | Jan. 1 | 5 32 | — 0 20 | 3 | 10.8 |
| " 25 | 7 56 | On meridian | 280 | 8.4 | " 15 | 5 0 | + 0 30 | 287 | 24.0 |
| " 27 | 8 57 | + 0 46 | 258 | 18.0 | " 17 | 5 2 | + 0 10 | 229 | 51.6 |
| " 30 | 5 58 | + 1 12 | 241 | 51.6 | Feb. 7 | 5 47 | On meridian | 175 | 15.6 |

It is noted in the observing book, on Dec. 23, that the forward motion of the spot seemed to have decreased. Great irregularities will be found in the motion of this spot, amounting from five to thirteen, and even in one case to twenty-nine degrees in a day. It may be that the mark observed on Jan. 17 was a different object altogether, otherwise a large jump has occurred there.

This mark, which lasted at least from the end of August, 1880, seems now to have disappeared, as no traces of it have been seen for over fifteen days. The mean period of rotation of this mark equals $9^h 51^m 8.30^s$.

MARK G.

Another very conspicuous spot, or rather a series of spots, was also carefully watched from the end of October to the end of December, after which it disappeared.

On Oct. 28, 1880, great changes occurred in the equatorial belt, especially on its northern half, the white, cloudy forms of the central zone changing their shape. At the same time, the delicate rosy color between the cloudy belt near the northern border of the equatorial zone assumed an intensity of color rarely seen, and almost equal to that of the red spot, although of a different shade. While these changes were going on, a row of five black spots, some of which resembled closely the shadows of satellites in transit, only not quite so black and not so sharp in outline, was observed in the northern hemisphere of the planet, forming part of the gray band nearest to the equatorial belt on that side. The first spot of the series on the preceding side was on the central meridian at the same time that the following end of the red spot crossed this line on the 28th of October.

The gray band on which these black spots were formed underwent very rapid changes, and on the following days new spots, similar to the first, appeared, mostly in pairs, at irregular intervals on the following side of the former, until at least one half of the whole circumference of Jupiter was covered with round black spots, differing but little in size and in depth of tint.

Owing to the formation of these new spots, it was difficult to know with certainty which was the one that had been observed before passing the central meridian, and possibly errors may thus have been made in mistaking one for the other, especially from the 28th of October to the 16th of November.

The following table gives the dates and times of the passages of the preceding spot of the row across the central meridian.

| 1880. | h. m. | | h. m. | | ° / | 1880. | h. m. | | h. m. | | ° / |
|---------|-------|----|-------|----|----------|--------|-------|----|-------|----|----------|
| Oct. 28 | 7 | 2 | + 0 | 8 | 349 48.0 | Nov. 8 | 7 | 20 | + 0 | 40 | 218 49.2 |
| " 31 | 13 | 22 | - 0 | 40 | 311 49.2 | " 10 | 7 | 25 | + 1 | 0 | 163 30.0 |
| Nov. 1 | 8 | 48 | + 0 | 42 | 296 56.4 | " 17 | 6 | 30 | + 0 | 55 | 104 56.4 |

Great irregularities will be found in the apparent motion of this mark, and possibly a different spot may have formed on the preceding side, thus producing a jump. This may have occurred between the 8th and 10th of November, when the apparent motion was at the rate of 27.5° ; i. e. this spot gained 27.5° a day on the red spot. The mean period of rotation of the planet obtained from the observation of 49 rotations of this mark equals $9^h 47^m 6.10^s$.

MARK H.

On Nov. 19, the fifth or sixth spot from the preceding one became considerably darker and more characteristic than the others, projecting a little outside of the row on the north side. It was separated from the next spot on the following side by a larger interval occupied by a brilliant sort of bridge, strongly resembling some of the brilliant faculae which oftentimes separate sun-spots in activity. This facula-like object, together with a sort of bright ring almost encircling it, gave to that spot and the following one a very peculiar look, and bore a striking resemblance to some of the solar spots, which was very suggestive.

In the beginning of December, some changes occurred in these spots, a long and narrow appendage being added to the preceding one, giving it the appearance of a tail preceding it to the southwest for a distance three or four times its own diameter.

On December 16, the black spots began to enlarge considerably, while at the same time they became diffused on their border and much

less dark than they had been, some of them becoming so pale that they could hardly be distinguished. After a few days these enlarged spots, which had become numerous and encircled the planet, disappeared altogether, leaving in their place a broad belt, having a strong resemblance to the equatorial belt, except that it was only half as wide, and having a central cloudy white band enclosed on each side by a space tinted with the delicate pink color which distinguishes the equatorial zone.

I shall here remark that every time I have observed great changes in the configuration of the markings of the surface of Jupiter, they were accompanied by an increase in the intensity of the rose color of that part of the equatorial belt nearest to the place of disturbance. At the time the black spots above described made their appearance, simultaneously with the increase of intensity of the rosy belt, a slight tinge of red was noticed under the black spots, in the northeast, this tinge occupying a great portion of the area constituting the north polar cap. This pinkish tinge went on increasing somewhat in intensity as well as in extent until Nov. 1, when it culminated, then extending from the first gray band north of the one where the black spots had formed to the north limb. The pink tinge then gradually decreased in intensity and in extent, and was last seen on the 24th of November, after which it was confined to the northern pink belt already described. The pink color of the equatorial belt towards the north seemed under the same influence, since it culminated also in intensity on Nov. 1, after which date it gradually decreased until it resumed the same delicate tint with the other parts.

The formation of this series of black sun-spot-like forms, with their subsequent development into a broad pink-tinted belt, is very instructive, inasmuch as it shows us how the forces creating such belts are acting. This action on Jupiter is not without some suggestive points of resemblance to the action creating the similar openings of the Sun's photosphere, which we call sun-spots. As we know, the sun-spots not only have a tendency to form into groups, the axis of which is parallel to the solar equator, — or, if it is not exactly so, it soon attains this parallelism, — but, again, all the groups of one epoch keep on the same parallel of latitude on each side of the equator. If on the Sun the forces creating the spots should increase and continue for some time with the same intensity as seems to be the case on Jupiter, a continuous belt of spots would surround the Sun, and finally a broad belt would result by the breaking up of the thin walls separating every individual spot. On the Sun, of course, the forces required to produce

such an effect must necessarily be more powerful than on Jupiter, since the photosphere of the Sun is undoubtedly much thicker than the cloudy atmosphere of Jupiter, and of a different nature.

The following table gives the time of the passages on the central meridian of the second spot described, that is, the sun-spot-like mark.

| 1880. | h. m. | h. m. | ° | ' | 1880. | h. m. | h. m. | ° | ' |
|---------|-------|--------|-----|------|--------|-------|--------|-----|------|
| Nov. 19 | 8 5 | — 0 40 | 103 | 33.6 | Dec. 3 | 5 52 | + 0 15 | 329 | 9.6 |
| " 22 | 4 34 | + 1 18 | 67 | 58.8 | " 9 | 7 34 | — 0 42 | 215 | 20.4 |
| " 24 | 5 58 | + 0 17 | 59 | 56.4 | " 14 | 5 13 | — 0 28 | 162 | 21.6 |
| " 26 | 7 13 | — 0 27 | 46 | 30.0 | " 16 | 6 21 | — 1 6 | 144 | 32.4 |
| " 30 | 8 10 | — 1 0 | 321 | 3.6 | | | | | |

The apparent motion of this spot is still more irregular than that of the passages of spot G, and varies from 2.3° to 21° a day; and between Nov. 30 and Dec. 3, the motion was even retrograde at the rate of 2.7° a day, which means that during these three days this spot had a longer period of rotation than the red spot has. The mean period of rotation of Jupiter as derived from the observation of this spot is $9^{\text{h}} 47^{\text{m}} 30.90^{\text{s}}$.

MARK I.

The object to be now considered is the preceding extremity of a remarkable white spot observed towards the end of November, 1880, inside the equatorial belt, near its southern border, and situated at about the same latitude as the mark F above described. On Nov. 26, at $6^{\text{h}} 46^{\text{m}}$, this mark was apparently under the following end of the great red spot. After Dec. 10, some changes occurred on and around this spot, and from that time it was lost.

The following are the dates and times of its passages on the centre of the disk.

| 1880. | h. m. | h. m. | ° | ' | 1880. | h. m. | h. m. | ° | ' |
|---------|-------|--------|-----|-----|--------|-------|--------------|-----|------|
| Nov. 26 | 6 4 | + 0 42 | 5 | 6.0 | Dec. 7 | 8 44 | + 0 45 | 315 | 18.0 |
| " 30 | 8 10 | — 1 0 | 357 | 3.6 | " 8 | 4 29 | + 0 50 | 311 | 38.4 |
| Dec. 3 | 5 32 | + 0 35 | 317 | 9.6 | " 10 | 6 2 | On meridian. | 308 | 52.8 |

The apparent motion of this mark is also irregular, and varies from 0.5° to 13° a day, the largest apparent motion having occurred between the 30th of November and the 3d of December.

The mean period of rotation of the planet as obtained from the observation of this mark is $9^{\text{h}} 52^{\text{m}} 52.90^{\text{s}}$.

MARK J.

The mark of which the passages on the central meridian are here tabulated is the preceding end of a conspicuous white cloudy form belonging to the southern side of the equatorial belt. This mark occupied very nearly the same parallel of latitude as did the marks F and I, already described. On Nov. 8, at 10^h 35^m it was on the central meridian with the centre of the great red spot. After Nov. 18, this mark changed so much that it could no longer be recognized among the other forms of the cloudy belt of the equator.

| 1880. | h. m. | | h. m. | | ° | ' | 1880. | h. m. | | h. m. | | ° | ' |
|--------|-------|------|--------------|--|-----|------|---------|-------|------|-------|----|-----|------|
| Nov. 8 | 10 | 35 | On meridian. | | 335 | 49.2 | Nov. 14 | 4 | 30 | + 1 | 25 | 299 | 6.0 |
| " | 9 | 5 52 | + 0 28 | | 315 | 28.8 | " | 16 | 5 52 | + 1 | 15 | 289 | 58.8 |
| " | 11 | 7 10 | — 0 10 | | 303 | 57.6 | " | 18 | 7 29 | + 1 | 18 | 289 | 48.0 |

The considerable apparent motion between the 8th and 9th of November must be very nearly correct, as both observations were carefully made, and while the mark was on the central meridian. The jump made on that day was over 20°; after that, the mean forward motion was only about 3° daily.

The mean period of rotation of Jupiter as obtained from this mark would be 9^h 52^m 15.0^s.

MARK K.

Towards the beginning of October, 1880, the red spot was preceded by a long grayish band, cut sharply and obliquely at its preceding end, and from there extending to within a few degrees of the preceding end of the red spot. As this band was situated only a few degrees more to the south than the red spot, I thought it worth while to study its behavior. After Oct. 13, this band contracted rapidly, both of its extremities either retreating towards each other or dissolving; but after the 25th it expanded again lengthwise until the 31st, and was lost entirely the following day.

The passages here given are those of the preceding extremity of this band.

| 1880. | h. m. | | h. m. | | ° | ' | 1880. | h. m. | | h. m. | | ° | ' |
|--------|-------|-------|-------------|---|-----|------|---------|-------|-------|--------------|---|-----|------|
| Oct. 3 | 8 | 57 | + 0 28 | | 252 | 21.6 | Oct. 25 | 7 | 6 | On meridian. | | 260 | 52.8 |
| " | 12 | 11 25 | on meridian | | 258 | 21.6 | " | 31 | 11 42 | + 1 | 0 | 251 | 49.2 |
| " | 15 | 8 59 | " | " | 262 | 12.0 | | | | | | | |

Contrary to the behavior of all the other markings, the apparent motion of this object, when compared with that of the red spot, was retrograde at first, and direct at last.

The rotation period obtained from this object equals 9^h 55^m 22.5^s.

MARK L.

Soon after the gray band K, above described, had disappeared, some changes occurred in the markings of that particular region of Jupiter. On Nov. 15, a large oval gray spot, resembling the red spot in size and in shape, made its appearance at the same place which the gray band had occupied. On its southern side this oval spot was edged with a narrow bright border, which made it appear more sharply defined on that side. This oblong spot has been carefully observed, and was lost in the beginning of February.

The following are the dates and times of the passages of the centre of this spot on the central meridian.

| 1880. | h. m. | h. m. | o | ' | 1881. | h. m. | h. m. | o | ' |
|---------|-------|--------------|-----|------|--------|-------|--------------|-----|------|
| Nov. 15 | 9 37 | — 1 30 | 275 | 31.2 | Jan. 3 | 4 15 | + 1 15 | 255 | 36.0 |
| " 16 | 5 32 | + 1 35 | 277 | 58.8 | " 7 | 8 5 | On meridian. | 276 | 6 6 |
| " 30 | 6 28 | + 0 42 | 259 | 51.6 | " 15 | 4 10 | + 1 20 | 257 | 34.0 |
| Dec. 10 | 4 32 | + 1 30 | 254 | 52.8 | " 17 | 6 8 | — 0 56 | 269 | 27.6 |
| " 17 | 5 33 | On meridian. | 265 | 4.8 | " 22 | 4 37 | + 1 0 | 246 | 32.4 |
| " 19 | 7 0 | " | 258 | 36.6 | Feb. 2 | 4 57 | + 0 40 | 113 | 42.0 |
| " 22 | 4 28 | + 0 36 | 258 | 10.8 | " 4 | 6 40 | + 0 55 | 116 | 42.0 |

It is doubtful whether the observation of Feb. 2 relates to the same marking as that last seen on Jan. 22, although the object appeared exactly like it in form and in size. On Jan. 31, at 5^h 38^m, a dark oval spot was seen on the east limb; undoubtedly this was the same object seen on the 22d, and no other spot was to be seen towards the west, or at any other place. If the spot observed on Feb. 2 had then existed, it would have been less than 2^h 30^m distant from and preceding the first, and therefore visible west of the centre of the disk. The spot observed on the 2d, then, must have been either the old one, having made a jump of 118° in two days, or a new form, which appeared between the 31st of January and the 2d of February. It seems probable that the last supposition is the true one.

The apparent proper motion of the spot K has in general been slow and irregular, being sometimes retrograde. If, however, we take its position when first observed on Nov. 15, and that of Jan. 22, when it was last seen, we have a difference of nearly 29° for its direct motion during this interval.

The rotation of Jupiter derived from the observation of this mark would be 9^h 55^m 14.60^s.

Below is a table giving the approximate period of rotation which we would give to Jupiter if it were determined from the observations of the

spots we have described in this paper. The period of each spot is the mean of the number of rotations during which each one was individually observed.

APPROXIMATE PERIOD OF ROTATION OF THE MARKS OBSERVED, IN THEIR ORDER OF DECREASE.

| | | | | Mean period of rotation obtained from | | |
|---|------|----------------|------------------|---------------------------------------|---|------------|
| | | | | h. m. s. | | |
| E | From | Sept. 25, 1878 | to Feb. 13, 1881 | 2108 rotations equal | 9 | 55 38.57 |
| D | " | April 14, 1877 | " Aug. 21, 1879 | 2076 | " | 9 55 36.70 |
| C | " | " 11, 1877 | " Sept. 10, 1878 | 1249 | " | 9 55 35.88 |
| K | " | Oct. 3, 1880 | " Oct. 31, 1880 | 68 | " | 9 55 22.05 |
| L | " | Nov. 15, 1880 | " Jan. 22, 1881 | 164 | " | 9 55 14.60 |
| I | " | " 26, 1880 | " Dec. 10, 1880 | 34 | " | 9 52 52.90 |
| J | " | " 8, 1880 | " Nov. 18, 1880 | 24 | " | 9 52 15.00 |
| F | " | " 16, 1880 | " Feb. 7, 1881 | 202 | " | 9 51 8.30 |
| H | " | " 19, 1880 | " Dec. 16, 1880 | 66 | " | 9 47 30.90 |
| G | " | Oct. 28, 1880 | " Nov. 17, 1880 | 49 | " | 9 47 6.10 |
| A | " | May 19, 1876 | " May 21, 1876 | 5 | " | 9 47 0.00 |
| B | " | " 25, 1876 | | $\frac{1}{2}$ | " | 2 0 0.00 |

This table shows conclusively that the different spots and markings studied in this paper did not return to the meridian in the same interval of time, each having a distinct and separate period of rotation, varying from $9^h 55^m 38^s$ to 2^h . Not only each one had a distinct period of rotation, but, again, it is shown by the other tables that the very same spot had different periods of rotation, varying from day to day, and this sometimes considerably. On some days the spots moved rapidly, and made great jumps forward, while on others they moved slowly, and even seemed to retrograde. For the last ten years I have closely observed Jupiter, and the same phenomena have occurred; therefore the proper motion of the markings of the planet is not an accident. In 1876, as already stated, the changes were much more rapid, and on a larger scale, than they have been since. During that year, not a spot or mark, save in one instance, could be recognized on the following day.

Since no marking which could be taken for reference on the surface of Jupiter is absolutely fixed on the planet, it is impossible to obtain the exact period of rotation of the solid nucleus of this body; and it is therefore probable, if not absolutely certain, that no one has yet succeeded in obtaining it. Unless some great changes occur in the constitution of the planet, it is not likely that astronomers are soon to obtain that exact period. The period of rotation which we obtain now is the period of clouds, similar in appearance to those of our earth, floating in a dense atmosphere: the period is longer or shorter,

according to the velocity and direction of motion of the mark we take for reference in our observations ; this is all.

But if it is impossible to obtain the true period of rotation of Jupiter in the present condition of the planet, it is possible to approach it, and to come within narrow limits of the true period, by the observation of a great number of markings, having great permanency, and lasting unchanged for a long period, like the markings C, D, and E. It seems probable that this last, the great red spot, gives us, about as nearly as we ever can obtain it, the period of rotation of Jupiter ; although the period of this spot is far from being perfectly uniform, as it is certainly endowed with a motion of its own, which becomes very perceptible on some days, — a fact which is easily established from the changes of form of that spot described above. It is remarkable that the period of the red spot, greater at first, has decreased afterwards, and then increased at last so as to be very nearly equal to what it was at first. The mean period of this spot from Sept. 25 to Dec. 28, 1878, equals $9^h 55^m 43.61^s$; from Aug. 9 to Nov. 9, 1880, it equals $9^h 55^m 30.81^s$, and from Nov. 9, 1880, to Feb. 13, 1881, it equals $9^h 55^m 43.96^s$. The mean intermediate period was then very nearly 13^s shorter than were the first and last.

It is remarkable that of all the markings observed the red spot gives the greatest period of rotation to Jupiter ; next come the marks D and C, which also, like the red spot, had a long duration, and were on the south side and very nearly in the same latitude as this spot. These observations do not support the assumption, however, that the proper motion of the spots follows any law in regard to latitude, as is supposed to be the case with sun-spots ; for the spots G, which occupied about the same latitude in the north as the red spot occupied in the south, had a period over 8^m shorter than has this last. The markings A, F, H, and I, although very nearly on the same parallel of south latitude, had different periods, the extreme of which differed by nearly 6^m . The oval spot K, although in higher southern latitudes than the red spot, yet had a shorter period of rotation, and we have shown that the angular mark A, of 1876, observed on the southern border of the equatorial belt, had a period of 2^h only, while all the markings of that hemisphere extending up to the pole had very nearly the same rapid proper motion. From the behavior of F, G, and H, it would seem that, all being equal, the period of rotation is shorter when the spot is new than when it has lasted for some time.

I have shown that the surface of Jupiter, like that of the Sun, has years of calm and years of great disturbance. In the year 1876, the

equatorial belt varied so much that on some days it appeared fully three times as broad as it did on others, extending to unusually high latitudes north and south, which at times reached 40° and 45° on either side of the equator. On several occasions, this broad, rosy equatorial belt did not appear symmetrically distributed on the sides of the equator, but was more or less one-sided, the southern being usually the side where it was most extended. In 1877, the disturbances on Jupiter were few and on a small scale, and after the middle of June the surface was remarkably quiet, the few changes noticed occurring principally within the equatorial belt. This state of quietness has continued till now, with the exceptions of the appearance of the red spot in 1878, which occurred without any great commotion or changes of the surface, and the bursting out of the row of round black spots in October, 1880, which subsequently developed into the broad rosy belt now seen in the northern hemisphere of the planet.

In regard to the question put forward by Mr. Marth, in the "English Mechanic," whether anything is known of the red spot in 1876-77, and whether it was then seen and observed, I can only give the following answer. In the year 1876 I began observing Jupiter on May 16, and observed it on every clear night as late as Oct. 19, and made during that interval 125 drawings of the planet. Nothing resembling the red spot in the slightest degree was seen during these observations. In 1877 the observations were begun on April 11, and continued on every clear night as late as Dec. 9, 142 drawings being made of its configuration, and no traces of the red spot were seen. In 1878, only a few observations were made before September; two drawings were made in February, two in March, one in May, one in June, and fifteen in September, previously to my seeing the red spot on the 25th of that month. My observations, therefore, do not give any information about this interesting object before Sept. 25, 1878. The negative evidence given by my observations amounts almost to certainty that the red spot did not exist before the year 1878.

CAMBRIDGE, March 5, 1881.